Katarzyna SZWEDZIAK, **Joanna MOCZKO**
Opole University of Technology, Department of Biosystems Engineering, Opole, Poland
e-mail: k.szwedziak@po.opole.pl

Received: 2018-11-19 ; Accepted: 2018-11-29

THE USE OF A VIBRATING FLUIDIZED BED DRYER FOR THE MANUFACTURE OF HIGH-PROTEIN PRODUCTS

Summary

Dairy industry liquid products have short terms of validity. Therefore, it has become very popular to produce dairy products in the form of powder. This powder is obtained by a two-step spray drying method. At an initial stage, the raw material is preliminarily dried in a spray dryer (to get 10% moisture). At the following stage, it is thoroughly dried in a vibrating fluidized bed dryer (3-4% moisture). Fluidization is a process, in which dry grains of solid contact fluid to generate a fluidized bed that behaves similarly to boiling liquid. Owing to this process, powder of improved physicochemical properties is formed. The aim of our study was to describe the construction and working principles of a whey vibrating fluidized bed dryer.
***Key words**: vibrating fluidized bed dryer, fluidization, drying, whey*

WYKORZYSTANIE WIBROFLUIDYZATORA DO PRODUKCJI PREPARATÓW WYSOKOBIAŁKOWYCH

Streszczenie

Płynne produkty przemysłu mleczarskiego mają krótkie terminy przydatności do spożycia. Dlatego popularne stało się produkowanie sproszkowanych produktów mlecznych. Do produkcji tych proszków stosuje się metodę dwustopniowego suszenia rozpyłowego. W pierwszej fazie surowiec jest suszony w suszarce rozpyłowej (do 10% wilgotności), a następnie dosuszany w wibrofluidyzatorze (3-4% wilgotności). Fluidyzacja to proces kontaktowania się suchych ziaren ciała stałego z płynem, aby wytworzyć złoże fluidalne, które zachowuje się podobnie do wrzącej cieczy. Dzięki temu procesowi powstaje proszek o lepszych właściwościach fizykochemicznych. Celem niniejszej pracy jest opisanie budowy i zasady działania wibrofluidyzatora do serwatki.
***Słowa kluczowe**: wibrofluidyzator, fluidyzacja, suszenie, serwatka*

1. Introduction

Dairy industry products, especially liquid ones, have different, often short terms of validity. Liquid whey undergoes a rapid fermentation, therefore it is very popular to convert it into whey powder. As a result, it is easier to transport and store. On an industrial scale, whey powder is obtained by drying in roller driers and spray drying. The product obtained by the first method is characterized by poor solubility and is of inferior quality because high temperature of drying causes protein denaturation. Spray drying allows for the production of whey powder having a good quality and good solubility (the ingredients have practically the same form as in the starting raw material). The moisture content of whey powder should remain at the level of 3-4%. The most economical way of spray drying is multi-stage drying using vibrating fluidized bed dryers [10].

2. Aim and scope of the study

The aim of our study was to describe the construction and operation principles of whey vibrating fluidized bed dryer used to dry whey powder obtained by means of spray drying, which will dissolve rapidly without stirring and will not stick to the walls of the package. Sticking of the powder to the walls of equipment and packages can be caused by the presence of electrostatic charge. Such charging may cause a deterioration of the powder solubility in water and an increase in the dissolution time. The elimination of electrostatic charging of the powder will improve the dissolution rate of the powder in water.

3. Properties of whey

Whey is a by-product of milk processing. Whey can be divided into rennet whey, which is sweet and acid whey, which is sour. Sweet whey is easy to process, while the problems in sour whey are calcium and lactic acid. In Fig. 1 a classification of milk components in an exemplary product, which is cheese, is presented. In Table 1 and 2 the chemical composition of sweet and sour whey as well as the composition of liquid and powdered whey [2] are presented.

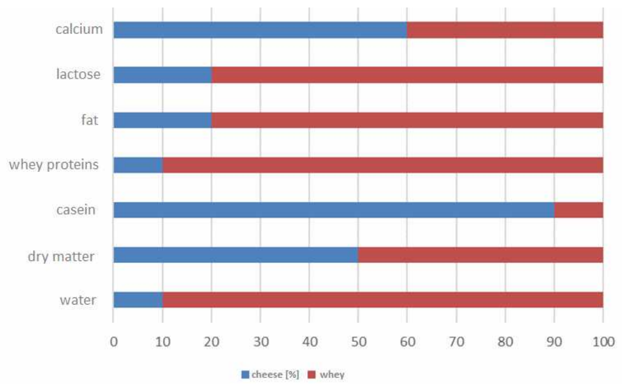


Fig. 1. Classification of milk components [2]
Rys. 1. Klasyfikacja składników mleka [2]

Table 1. Chemical composition of sweet and sour whey [2]
Tab. 1. Skład chemiczny serwatki słodkiej i kwaśnej [2]

	Sweet whey	Sour whey
Dry matter	63-70	63-70
Lactose	46-52	44-46
Proteins	6-10	6-8
Calcium	0.4 – 0.6	1.2-1.6
Phosphates	1-3	2 -4.5
Lactates	2	6.4
Chlorides	1.1	1.1

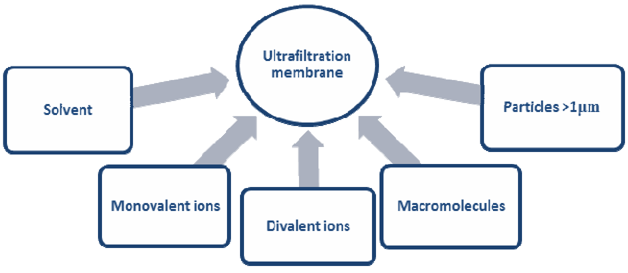
Tab. 2. Composition of liquid and powdered whey [2]
Tab. 2. Skład serwatki płynnej i sproszkowanej [2]

Product	Protein	Lactose	Mineral salts
Sweet whey	6-10	460-52	2.5-4.7
Sour whey	6-8	44-46	4.3-7.2
WPC – 35 [g/100g]	35	50	7.2
WPC[g/100g]	65-80	1-4	3-5
WPI [g/100g]	88-92	□ 1	2-3

4. Whey drying process

Whey powder permeate is obtained from fresh cheese whey by ultrafiltration, and a subsequent spray drying. Whey is neutral in taste, therefore it can act as a filler and water-binding component. The first step of whey drying is membrane ultrafiltration. Currently, in addition to ceramic (inorganic, mineral) membranes, membranes of organic origin (polymeric membranes) are used to fractionate milk proteins. The most commonly used organic membranes are membranes made of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). Polymeric membranes also belong to the most commonly used ones in UF. A definite advantage of organic membranes consists in their lower cost and lower energy demand compared to ceramic membranes. Unfortunately, polymeric membranes have quite low chemical stability and a shorter service life. In turn, ceramic membranes are very resistant to extreme chemical and physical conditions: they can operate in a pH range from 0.5 to 13.5 and at temperatures above 100°C. However, in the case of ceramic membranes, it is very important to perform temperature changes in a gradual manner (<10°C per minute) to avoid breaking of the membranes. [20] The use of ultrafiltration allows for the production of serum protein concentrates (SPCs) with a protein content of 34% and 80%, equivalent to whey protein concentrates (WPC). However, it should be remembered that due to the differences in the composition between SPC and WPC, the functional and sensory properties of these products will also be different [9, 12].

The scheme of membrane ultrafiltration operation is shown in Fig. 2.



Source: own work / Źródło: opracowanie własne

Fig. 2. The scheme of membrane ultrafiltration operation
Rys. 2. Schemat działania membran ultrafiltracyjnych

Ultrafiltration membranes are permeable to sugar, salt, water molecules, and retain proteins and larger particles, therefore they are used for filtration of liquid whey

5. Spray drying

Spray drying is a process by which a powdered product is formed from the starting liquid raw material (a solution or a suspension).

During the spray drying process four stages can be distinguished:

- spraying the raw material into a mist - spraying the liquid consists in dispersing the raw material with a nozzle or rotating disk to form microdroplets, which form a so-called “mist” (millions of droplets with a diameter of 10-300 µm).
- contact of the resulting drops with a hot drying medium,
- evaporation of the solvent,
- separation of the powder from the air stream.

The spraying of the liquid raw material takes place in the dryer chamber, where the liquid contacts the hot drying medium. High temperature, transferred to the droplets of the sprayed liquid, is contacted with a film-forming substance, thanks to which thermolabile components are less exposed to its action. With the increase in the degree to which the solvent evaporates, the diameter of a dried drop decreases, and the concentration of solid substances on its surface increases. Depending on the joint movement of the hot drying air and the sprayed material in the chamber, co-current, counter-current and mixed-flow dryers can be distinguished. In industry, the most common are dryers operating with co-current direction of material and air flow. Thanks to this, rapid evaporation takes place, which shortens the contact time of the material with high temperature. Subsequently, the dried particles are transported to the dryer of a cyclone by means of drying air, in which the powder resulting from the drying process is separated from the moist air and transferred to the receptacle. The product that does not remain in the cyclone is removed from the drying air by means of a filter. In Fig. 3 and 4 a scheme of a spray dryer is presented [6, 9].

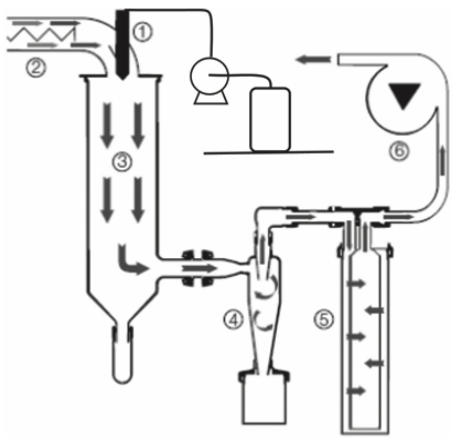


Fig. 3. A scheme of the BÜCHI B-290 spray dryer [6, 9]: 1 – a pneumatic nozzle spraying the solution delivered by a peristaltic pump, 2 – a drying air heater, 3 – a drying chamber, 4 – a cyclone for extracting powder, 5 – an exhaust air filter, 6 – an aspirator forcing the drying air flow
Rys. 3. Schemat suszarki rozpyłowej BÜCHI B-290 [6, 9]: 1 – dysza pneumatyczna rozpylająca roztwór dostarczony przez pompę perystaltyczną, 2 - nagrzewnica powietrza suszącego, 3 – komora suszenia, 4 – cyklon do ekstrakcji proszku, 5 – filtr powietrza wylotowego, 6 – aspirator wymuszający przepływ powietrza suszącego

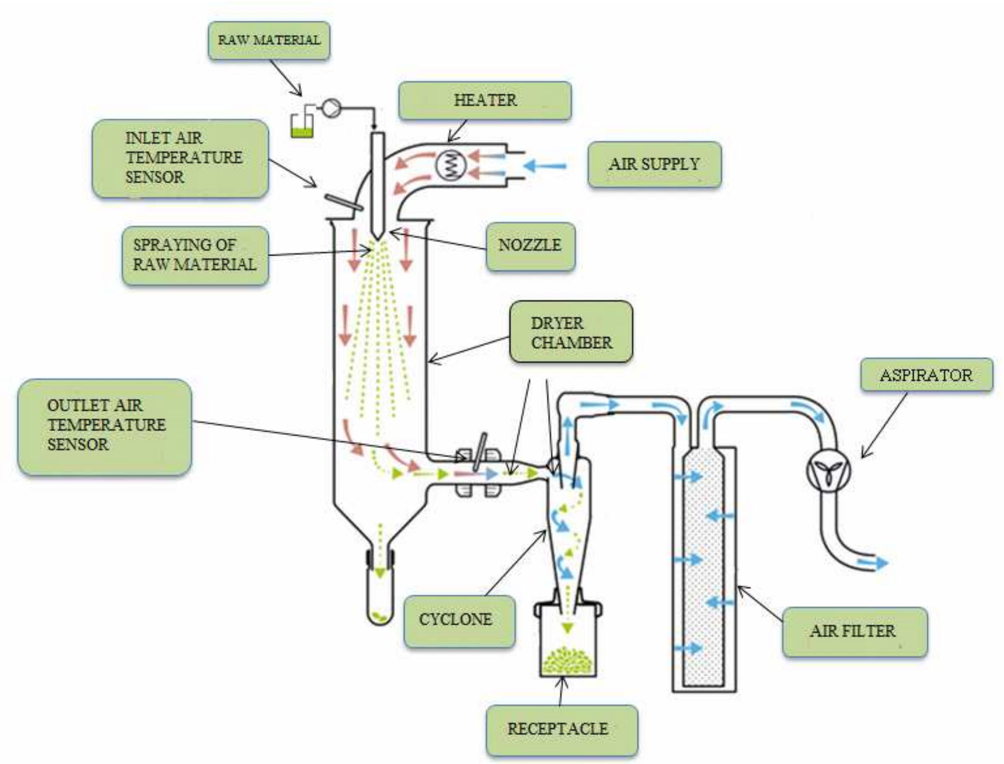


Fig. 4. A scheme of a spray dryer [6, 9]
Rys. 4. Schemat działania suszarki rozpyłowej [6, 9]

6. Construction and operation principles of vibrating fluidized bed dryer

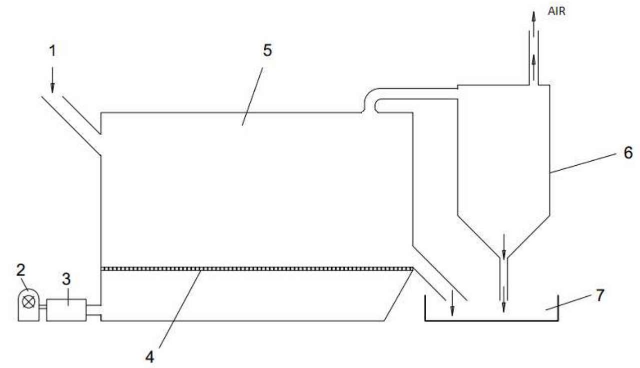
Fluidization is a process used for cooling, freezing and drying. In this method, a grain solid placed on a vibrating baffle is contacted with a fluid (fluidizing medium), which flows upwards forming a stream. To obtain a suspension with a high concentration of solid material, i.e. a fluidized bed, the so-called critical speed should be applied. This is such a flow rate of the fluidising medium, which will cause an overpressure that exceeds the pressure of the bed located on the baffle. Solid particles will start to move, increasing the volume of the bed. Further increase in the flow rate of the fluidising medium will loosen the bed, which will resemble a boiling liquid. Therefore, the solid state layer in the fluidized state is called a pseudo-boiling layer. In this state, a very complex – progressive and rotating – movement of molecules takes place. This allows obtaining a much larger area of interfacial contact, thanks to which it is easier to transfer heat and mass between the liquid, gas and solid phases [4, 8, 14, 15, 16].

Vibrating fluidized bed dryers have a wide range of applications in various industries. They are used for drying wet loose materials, including: coal, grain, coke, vegetables and fruits, organic dyes, whey, casein, lactose, etc. [8, 14]. In such equipment, the second drying of agglomerated and granulated products is also conducted [8].

In the expertise "New trends in food drying" by Witrowa-Rajchert various types of vibrating fluidized bed dryers used in the food industry are presented and described. Fluidised bed dryers can be divided into pulsed and vibrating fluidized bed dryers. In pulsed bed dryers, a fluidising medium is delivered in a pulsating (not continuous) manner. In case of vibrating fluidized bed dryers, the fluidising medium is delivered continuously at a speed exceeding the initial fluidization rate, and the fluidized bed is located on a vibrating baffle. Drying with an inert material may be an additional solution [16]. GEA Process Engineering INC.is one of the largest producers of powder recovery equipment. They offer many solutions for two-stage drying. They include devices such as: Vibro – Fluidizer® [17, 22], FSD™ Spray Dryer [18, 22], MSD™ Spray Dryer [19, 22] Compact Dryer™ Spray Dryer [20, 22] and Filtermat™ Spray Dryer [21, 22].

Vibrating fluidized bed dryers have an uncomplicated construction and operation scheme. A construction of a vibrating fluidized bed dryer is shown in Fig. 5.

Whey is pre-dried by means of spray drying to moist content of up to 10%, and delivered (1) to the drying chamber of the vibrating fluidized bed dryer (5), for further drying and agglomeration to obtain an instant product. The drying chamber has a flume-like shape, thanks to which the gas flow rate decreases with its rise [14]. The drying chamber is divided into two parts by a vibrating baffle (4) into which the wet whey powder falls. Most often, the baffles are made of perforated sheet metal. In the industry, other types of baffles are found. Lewicki reports that also bar baffles, felt baffles, as well as x sieve can also be used. The baffle is designed to evenly distribute the fluidizing medium in the fluidized layer. The vibration prevents the dried material from sticking to the baffle, enables obtaining a homogeneous fluidized layer and intensifies the drying process itself [8, 14]. The fluidizing medium is delivered under the baffle using a fan (2) and a heater (3). The appropriate fluid flow rate through the baffle causes a rise of loose whey and a formation of a fluidized bed having characteristics of a liquid. The appropriate fluid rate is one that significantly exceeds a free fall rate of solid particles in this fluid [8]. The whey powder dried to a value of 3-4% moist content is placed in a container for the finished product (7). In contrast, dusts that are generated in the vibrating fluidized bed dryer are transported to the cyclone (6). There, a separation of the dust from the air takes place. Whey dust is thrown into a container for the finished product, while the cleaned air leaves the cyclone through a specially designed opening [1, 3, 8, 13, 14].



Source: own elaboration based on [1, 5, 7, 14] / Źródło: opracowanie własne na podst. [1, 5, 7, 14]

Fig. 5. Construction of a vibrating fluidized bed dryer for drying whey: 1 – whey for drying, 2 – a fan, 3 – an air heater, 4 – a baffle, 5 – a drying chamber, 6- a cyclone, 7 – a container for the finished product
Rys. 5. Budowa wibrofluidyzatora do dosuszania serwatki: 1 – serwatka do dosuszenia, 2 – wentylator, 3 – nagrzewnica powietrza, 4 – przegroda, 5 – komora suszenia, 6 – cyklon, 7 – pojemnik na produkt gotowy

Temperature is one of the factors that significantly affect the rate of enzymatic reactions. The reaction rate increases with increasing temperature, but only to the value above which the protein denaturation begins. The rate of thermal denaturation of enzyme proteins is also directly proportional to the temperature. The optimum temperature is the one at which the enzymatic reaction proceeds the fastest, but at the same time no enzymatic protein denaturation is observed (Fig. 6) [11].

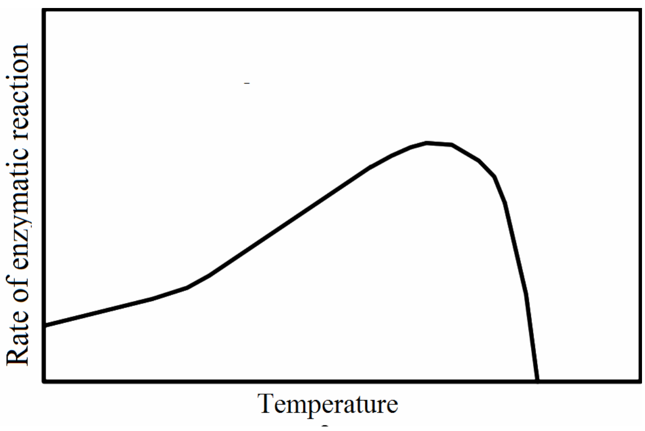


Fig. 6. Influence of temperature on the rate of enzymatic reaction [11]
Rys. 6. Wpływ temperatury na szybkość reakcji enzymatycznej [11]

The optimum temperature of enzymes activity depends on their origin. This value for animal enzymes is close to the body temperature. Enzymes of plant and microbiological origin reveal a wide variation in optimal temperature, even up to 90°C [11]. Knowledge of this issue will have an impact on the quality of raw materials obtained for the manufacture of high-protein products.

Basic requirements for protein products mainly concern:
- moisture,
- protein content,
- ash content,
- salmonella content.

7. Summary

The use of fluidized bed dryers in enterprises is profitable due to many advantages possessed by these dryers. The first most important consists in the simplicity of the device construction. Moreover, there is a possibility of adding an additional source of heat or cooling. The construction of vibrating fluidized bed dryers allows for high intensity of heat and mass transfer, thanks to which the solid has good contact with the liquid, can be thoroughly mixed and has almost the same temperature throughout the load [3, 4, 7, 8]. In addition, this dryer has high limits for overheating of individual pieces of dried material [7]. Low maintenance cost is the most important advantage of fluid bed dryers. Therefore, it is worth conducting further research on new applications of vibrating fluidized bed dryer in various branches of industry.

8. References

[1] Boss J.: Maszyny i urządzenia przemysłu spożywczego. Wyd. WSI, Opole, 1984.

[2] Brodziak A., Król J., Litwińczuk Z.: Ocena zawartości składników frakcji białkowej w różnych rodzajach mleka spożywczego. In: Właściwości produktów i surowców żywnościowych. Wybrane zagadnienia, 2014, 4-12.

[3] Chwiej M.: Aparatura przemysłu spożywczego. Maszyny i aparaty. PWN, Warszawa 1984.

[4] Ciesielczyk W., Pabiś A.: Przenoszenie pędu, ciepła i masy w układach fluidalnych. Laboratorium. Politechnika Krakowska im. Tadeusza Kościuszki, Kraków 1994.

[5] Fedoroszyn A., Dańko J., Smyksy K.: Parametry strumienia powietrza w urządzeniach wibrofluidyzacyjnych. IX Konferencja Odlewnicza Technical, Nowa Sól, 2006, 13-23.

[6] Gac J.M., Odziomek M., Sosnowski T.R., Gradoń L.: Doświadczalne i numeryczne badanie wytwarzania cząstek o różnej morfologii w procesie suszenia rozpyłowego. Inż. Ap. Chem., 2014, 53, 4, 241-242.

[7] Kerr W.L.: Handbook of Farm, Dairy and Food Machinery Engineering. Chapter 12. Food drying and evaporation processing operations. p. 317-354, Elsevier 2013.

[8] Lewicki P.P.: Inżynieria procesowa i aparatura przemysłu spożywczego. WNT, Warszawa 2005.

[9] Moczko J., Szwedziak K.: Wykorzystanie serwatki do produkcji odżywek wysokobiałkowych dla sportowców. Aktywność fizyczna – Badania i Rozwój Młodych Naukowców w Polsce. Monografie 2017. Wyd. Młodzi Naukowcy, Poznań 2017, 39-46.

[10] Popko R., Popko H., Hys L.: Przetwórstwo mleka. Nowe techniki i technologie przetwórstwa serwatki. Politechnika Lubelska, Lublin 1990.

[11] Samborska K.: Wpływ procesu suszenia rozpyłowego na degradację preparatu α-amylazy z Aspergilllus oryzae. Praca doktorska, Szkoła Główna Gospodarstwa Wiejskiego, Katedra Inżynierii Żywności i Organizacji Produkcji, Warszawa 2004.

[12] Skrzypek M.: Filtracja membranowa. Forum mleczarskie. https://www.forummleczarskie.pl/RAPORTY/214/.

[13] Spicer A.: Nowe metody zagęszczania i suszenia żywności. Materiały z Sympozjum zorganizowanego przez IUFoST. WNT, Warszawa 1980.

[14] Stabnikow W., Popow W.D., Łysianskij W.M., Riedko F.A.: Procesy i aparaty w przemyśle spożywczym. WNT, Warszawa 1978.
[15] Troniewski L., Palica M., Czernek K.: Przenoszenie pędu, ciepła i masy. Część I. Politechnika Opolska, Opole 2012.
[16] Witrowa-Rajchert D.: Nowe trendy w suszeniu żywności. Ekspertyza. AgEngPol, Warszawa 2009.
[17] http://www.gea.com/en/products/vibro-fluidizer.jsp, dostęp z dnia 27.02.2017.
[18] http://www.gea.com/en/products/fsd-spray-dryer.jsp, dostęp z dnia 27.02.2017.
[19] http://www.gea.com/en/products/gea-msd.jsp, dostęp z dnia 27.02.2017.
[20] http://www.gea.com/en/products/compact-dryer.jsp, dostęp z dnia 27.02.2017.
[21] http://www.gea.com/en/products/filtermat-spray-dryer.jsp, dostęp z dnia 27.02.2017.
[22] Milk Powder Technology – Evaporation and Spray Drying, Handbook GEA Process Engineering, Copenhagen 2010.

Acknowledgments:
The research was financed from the statutory resources of the Department of Biosystems Engineering of the Opole University of Technology.