Journal of Engineering Mechanics and Machinery (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/jemm.2024.090220
ISSN 2371-9133 Vol. 9 Num. 2

Design of Multi-stage Explosion Puffing Equipment for Fruit and Vegetable

Bo Wang[1], Haifeng Chen[1,*], Yanlong Hu[1], Bojun Chen[1], Bohao Zhang[1]

[1]College of Mechanical and Electrical Engineering, Shaanxi University of Science and Technology, Xi'an, China
897575704@qq.com
[*]Corresponding author

Keywords: Explosion; Multi-stage; Automatic; Puffing chamber

Abstract: To address issues such as low automation in the explosion puffing drying process for fruits and vegetables, a new explosion puffing equipment employing a multi-stage variable temperature and pressure differential method was designed. The equipment utilizes the gravity of the material and the opening and closing of heated knife valves to move the material sequentially from top to bottom through each stage of the puffing chambers, starting from the storage chamber. It employs a heat-conducting oil heating system and heated knife valves to jointly heat each stage of the puffing chambers, and uses vacuum equipment and a gas supply system to control the pressure of the entire equipment to achieve multiple puffing. This equipment can be combined with vacuum belt dryer and other equipment to form an automated puffing drying equipment. This research provides valuable reference for the improvement of explosion puffing equipment.

1. Introduction

The explosion puffing equipment is used to puff fruits and vegetables, which first applies a certain temperature and pressure to the material, and then quickly releases the pressure to make the moisture inside the material evaporate quickly to form a puffing effect, which preserves a host of nutritional characteristics while removing water, and the prepared product also has a crisp texture, so it has a broad application prospect [1]. Currently, major manufacturers mainly use manually operated single-stage puffing equipment to process material. This method has a long production cycle, low efficiency, and high labor intensity, making it difficult to meet the demands of large-scale processing and limiting the broader application of this technology [2-4]. In order to solve the above problems, scholars have carried out different degrees of research on the explosion puffing equipment, and Yu developed an infrared explosion puffing dryer, which applied infrared heating to improve the efficiency [5]. Liu developed a continuous instantaneous microwave puffing equipment to achieve rapid and centralized heating of materials through microwave generators [6]. Wang designed a puffing equipment with a jacket and a heat exchanger plate for co-heating, which has a higher heat transfer efficiency [7].

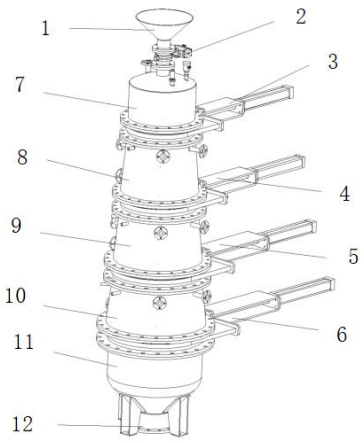
At present, the puffing of fruits and vegetables with variable temperature and pressure difference has not yet achieved large-scale automated production, and the production efficiency needs to be further improved [8]. In order to solve the problems of low degree of automation and poor production

efficiency of variable temperature and pressure difference puffing and drying, a new type of explosion puffing equipment for fruits and vegetables using multi-stage variable temperature and pressure difference puffing method was designed. This equipment can carry out continuous multi-stage variable temperature and pressure difference puffing of fruits and vegetables compared with the traditional puffing equipment, which can effectively improve the production efficiency and product quality, and the equipment can be combined with vacuum belt dryer and other equipment to realize the automatic production of fruit and vegetable dry materials. It is of positive significance for the continuous, automated and high-quality production of fruit and vegetable variable temperature and pressure difference puffing industry.

2. Structural composition and working principle

2.1 Structure of puffing equipment

The overall structure of explosion puffing equipment is mainly composed of feed hopper, pneumatic butterfly valve, storage chamber, first-stage puffing chamber, second-stage puffing chamber, third-stage puffing chamber, lower head, discharge port and heating knife valves at all levels. The heat conduction oil heating system, gas supply system and temperature detection equipment and pressure detection equipment inside the puffing chamber are connected to the puffing chamber at all levels; The material level detection device and pressure detection device inside the storage chamber; rack equipment, control system and vacuum system. Among them, the storage chamber and puffing chamber at all levels are the key equipment which are directly related to the production process and production quality of explosion puffing of materials. The structure of the multi-stage explosion puffing equipment is shown in Figure 1.



1-Feed hopper ,2-Pneumatic butterfly valve ,3-First-stage heating knife valve, 4-Second-stage heating knife valve ,5-Third-stage heating knife valve, 6-Fourth-stage heating knife valve, 7-Storage chamber, 8-First-stage puffing chamber, 9-Second-stage puffing chamber, 10-Third-stage puffing chamber, 11-discharging chamber, 12-discharge port

Figure 1: Explosion puffing equipment

2.2 How it works

The working process of the explosion puffing equipment is mainly divided into two stages: the starting process and the circulating working process: when the equipment is fed, it is necessary to

reach the specified state through the heating system and vacuum system before supplying the equipment, and this stage is the starting process. Once the equipment start-up process is complete, continuous feeding can be conducted through the feed hopper, either using sequential feeding equipment or manually. The equipment then operates continuously in a cyclic work process. The workflow is shown in Figure 2.

Starting process: (1) Close the pneumatic butterfly valve at the inlet first, and then start the vacuum pump to evacuate the storage chamber and the puffing chamber at all levels to the vacuum, and start the heat transfer oil heating system at the same time, so that the heat transfer oil can heat the puffing chamber at all levels. When the inside of the puffing chamber at all levels reaches the rated temperature, the internal insulation is insulated through the control system, and then the heating knife valve between the storage chamber and the puffing chamber at all levels is closed to isolate each other. (2) Open the pneumatic butterfly valve at the feed hopper, and the pretreated fruit and vegetable materials will be transported from the feed port to the storage chamber by the conveying equipment or manually, and the radar level sensor in the storage chamber will close the pneumatic butterfly valve to stop feeding when the radar level sensor senses that the material level is in the set position, and then start the vacuum pump until the storage chamber is vacuumed, and the first-stage heating knife valve will keep the fruit and vegetable materials warm. Cyclic working process: (3) Controlled by the system, the first-stage heating knife valve is opened, allowing materials in the storage chamber to fall into the first-stage puffing chamber. After the materials have been fully unloaded, the first-stage heating knife valve is closed to seal the first-stage puffing chamber. Then, the pneumatic butterfly valve at the feed inlet of the storage chamber is opened to refill and vacuum the storage chamber. At the same time, the intake valve connected to the first-stage puffing chamber is opened, gradually introducing clean inert gases such as nitrogen, carbon dioxide, or compressed air into the first-stage puffing chamber to reach the preset pressure. The internal heating equipment in the first-stage puffing chamber raises the temperature of the fruit and vegetable materials to the predetermined level. Once the pressure and temperature in the first-stage puffing chamber reach the set values, the system maintains the temperature and pressure for a period of time. Meanwhile, the air outlet of the second-stage puffing chamber is opened, connecting it to the vacuum condensation tank, which keeps the internal pressure of the second-stage puffing chamber in a negative pressure state (4) Open the two-stage heating knife valve, because the pressure difference between the first-stage puffing chamber and the second-stage puffing chamber will make the gas in the first-stage puffing chamber be discharged into the vacuum condensation tank through the gas outlet at the second-stage puffing chamber, and due to the change of pressure difference, the fruit and vegetable material can realize the first-stage variable temperature and pressure difference explosion, and the airflow generated by the pressure relief can promote the fruit and vegetable material from the first-stage puffing chamber to the second-stage puffing chamber, so as to prevent the blockage of the puffed material. (5) After the first puffing is completed, the control system first closes the second-stage heating knife valve and the valve at the air outlet of the second-stage puffing chamber, sealing the second-stage puffing chamber. Then, the fruit and vegetable materials that have fallen into the second-stage puffing chamber undergo a second round of heating and pressurization. The first-stage heating knife valve is controlled to release the materials from the storage chamber into the first-stage puffing chamber for heating and pressurization. After that, the pneumatic butterfly valve at the feed inlet is controlled to refill the storage chamber, followed by vacuuming (6) Repeating the above process, the materials can achieve step-by-step explosion from top to bottom. The materials in the third explosion chamber passes through the lower head and is discharged into the vacuum dryer. After drying in the vacuum dryer, the material is cooled and discharged.

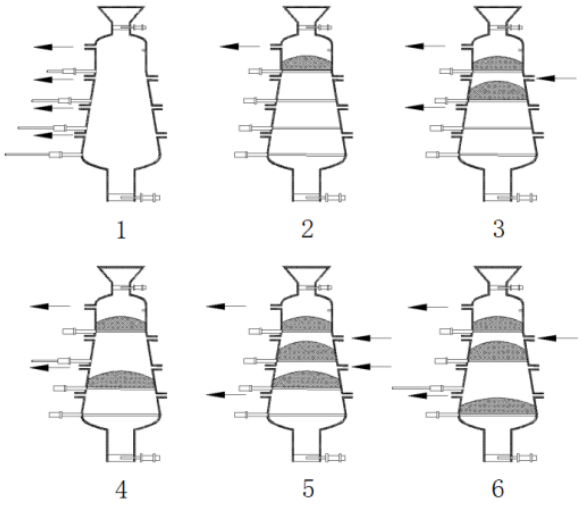
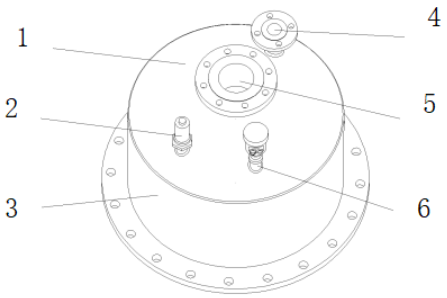


Figure 2: Workflow diagram

3. Structural design of key equipment

3.1 Design of storage chamber

The main structure of the storage chamber equipment is welded by using a cylindrical storage barrel of 304 stainless steel with a nominal diameter of 600mm and a butterfly-shaped upper head, and a gas extraction port, a feed pipe, a material level sensor and a pressure sensor are installed at the upper head. The upper head level sensor can detect the material level inside the storage chamber, so as to adjust the opening and closing of the valve at the feed port according to the detected signal to achieve accurate feeding in the chamber. The gas extraction port is connected to the vacuum pump through the pipeline, and the vacuum pump can be started to vacuum the storage chamber; The pressure sensor detects the air pressure in the chamber in real time to ensure that the evacuation phase is compliant. The lower end of the cylindrical storage barrel is connected with the heating knife valve through the flange, and the storage chamber and the first-stage puffing chamber can be connected through the opening and closing of the heating knife valve, so that the material can be unloaded from the storage chamber to the first-stage puffing chamber by its own gravity. The function of the storage chamber is to vacuum the material before entering the explosion bin, so as to reduce the oxidation of the material in the explosion stage of variable temperature and pressure difference. The structure is shown in Figure 3.



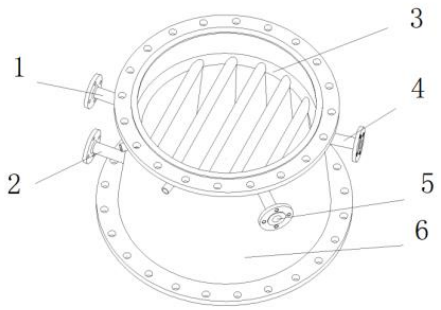
1-Upper head 2-Pressure sensor 3-Storage cylinder 4-gas extraction port 5-feed port 6-material level sensor

Figure 3: Diagram of storage chamber

3.2 Design of puffing chambers at all levels

The overall structure of the puffing chamber at all levels is composed of 304 stainless steel puffing chamber outer housing and inner jacket. The inlet and outlet of the heat transfer oil of the shell of the puffing chamber are connected with the heat transfer oil circulation system, and the inner heat transfer oil jacket is filled with heat transfer oil through the delivery of the oil pump. According to Fourier's law, the total heat transfer per unit time is proportional to the heat transfer area, so the inner jacket of the puffing chamber at all levels is arranged in the horizontal direction to increase the heat transfer area. According to the theory of convective heat transfer, it can be seen that the heat transfer coefficient in the turbulent state is much higher than that in the laminar flow state, so the heat transfer effect is enhanced by setting multiple baffles in the vertical direction of the jacket to improve the turbulence degree and flow path of the fluid, so as to improve the convective heat transfer coefficient. In order to prevent the blockage caused by the volume change of the product caused by the puffing production of fruit and vegetable variable temperature and pressure difference, the puffing chambers at all levels are conical table structures with narrow upper mouth and wide lower mouth, and the nominal diameters of the lower mouths of the first, second and third puffing chambers are 700mm, 800mm and 900mm respectively.

The puffing chambers at all levels are provided with air inlets and outlets. The air supply system pressurizes the interior by injecting inert gases such as CO_2 and N_2 into each chamber from the air inlet. The air outlets of the puffing chambers at all levels are connected with the vacuum tank through the pipeline system, and the pressure of each bin can be depressurized by opening and closing the valves at the outlets of the chambers at all levels. The maximum working pressure of the explosion bin at all levels is 1.5Mpa, and the safety valve interface is set to avoid danger or equipment damage. At the same time, each stage of the puffing chamber is equipped with a pressure sensor and a temperature sensor to transmit the collected signals to the workbench and monitor the status of the material in real time. Figure 4 shows the schematic diagram of the structure of the single-stage explosion bin.



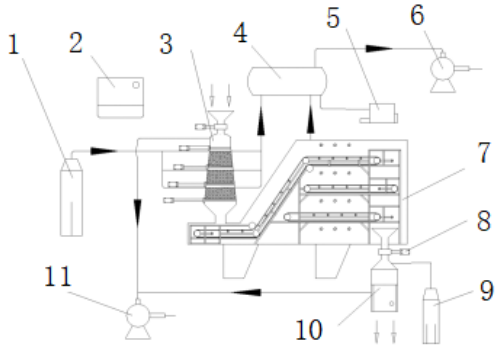
1-thermal oil inlet 2-thermal oil outlet 3-inner jacket 4-air inlet 5-air outlet 6-outer housing

Figure 4: Diagram of puffing chamber

4. Automated puffing and drying equipment

The new variable temperature and differential pressure puffing equipment designed in this paper can be combined with a variety of commonly used equipment such as vacuum belt dryer to form a joint production equipment for dried fruits and vegetables, as shown in Figure 5. The operational process is as follows: First, activate the thermal conductive oil system to bring the interior of the multi-stage explosion puffing equipment to the set temperature. At the same time, start the main and auxiliary vacuum pumps to create a negative pressure within the multi-stage explosion puffing equipment, the vacuum condensing tank, and the vacuum belt dryer. Next, open the pneumatic

butterfly valve on the multi-stage explosion equipment to begin feeding. The material first undergoes multi-stage temperature and pressure differential explosion within the multi-stage explosion puffing equipment. Afterward, it is dried and dewatered in the vacuum belt dryer. The dried material then falls into the cooling chamber, where it cools before being discharged.



1-gas supply system 2-thermal conductive oil system 3-multi-stage explosion equipment 4-vacuum condensation tank 5-water storage tank 6-main vacuum pump 7-vacuum belt dryer 8-pneumatic butterfly valve 9-liquid nitrogen tank 10-cooling chamber 11- auxiliary vacuum pump

Figure 5: The process flow of the joint equipment

5. Conclusion

In order to solve the problems of low efficiency and insufficient automation of puffing and drying of fruits and vegetables with variable temperature and pressure difference, a new type of puffing equipment was designed, which adopted the processing mode of multi-stage puffing to realize the efficient production of fruits and vegetables. A new type of puffing equipment and various commonly used equipment have formed an automated equipment for variable temperature and pressure differential puffing and drying of fruits and vegetables. This equipment has played a positive role in promoting the automation process of variable temperature and pressure differential puffing and drying.

References

[1] BI J F, HU L N, LV J, et al. Research advance of instant controlled pressure drop combined drying technology and dynamic optimization strategy [J].Journal of Food Science and Technology.2022.

[2] Bulantekin Ö, Kuşçu A, Eroğlu S. Application of novel methods for quality improvement in explosion puffing drying of apple snacks[J]. The Annals of the University Dunarea de Jos of Galati. Fascicle VI-Food Technology, 2023, 47(2): 9-27.

[3] KAUR R, KUMAR A, KUMAR V, et al. Recent advancements and applications of explosion puffing[J]. Food Chemistry, 2023, 403: 134452.

[4] YANG H,WU H B,JIN X W, et al. Effects of different pretreatment methods on quality of jujube chips produced by explosion puffing drying[J]. Food Research and Development, 2023,44(12):36-43.

[5] YU X, ZHANG Z, SUN Q, et al. Experimental and CFD Simulation Studies of Infrared Explosion Puffing Dryer[C]//2022 ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers, 2022: 1.

[6] LIU C, CHEN H F, YI F L, et al. A Study on a Continuous Type of Transient Microwave-explosion-puffing Equipment [J]. Packaging and Food Machinery,2009, 27(03):15-17+39.

[7] WANG L. Study on the Mechanism and Equipment Design of High-pressure Infiltration Puffing Drying for Panax Quinquefolium [D]. Shaanxi University of Science & Technology,2020.

[8] YI J Y, ZHOU L Y, BI J F, et al. Influence of number of puffing times on physicochemical, color, texture, and microstructure of explosion puffing dried apple chips[J]. Drying Technology, 2016, 34(7): 773-782.