



## Construction and Application of Fixed Bed, Fluidized Bed and Fluidized Drying Comprehensive Experiment

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### Abstract

In order to establish a research-based experimental platform for students to fully mobilize initiative and learning creativity, it is necessary to establish design and exploratory experiments to highlight independent exploration and innovation. Through experimental device improvement and material screening, the three parts of fluidization curve measurement, fixed bed drying and fluidized bed drying of spherical molecular sieve are integrated into an organic entirety. Especially, the traditional basic experiment is promoted to a design and research experimental project. Results show that students experimental design ability and comprehensive quality have been improved, and it also stimulated their learning interest, cultivated the creative ability.

**Keywords:** Experimental design; Drying; Spherical molecular sieve; Chemical engineering experiment.



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### 1. Introduction

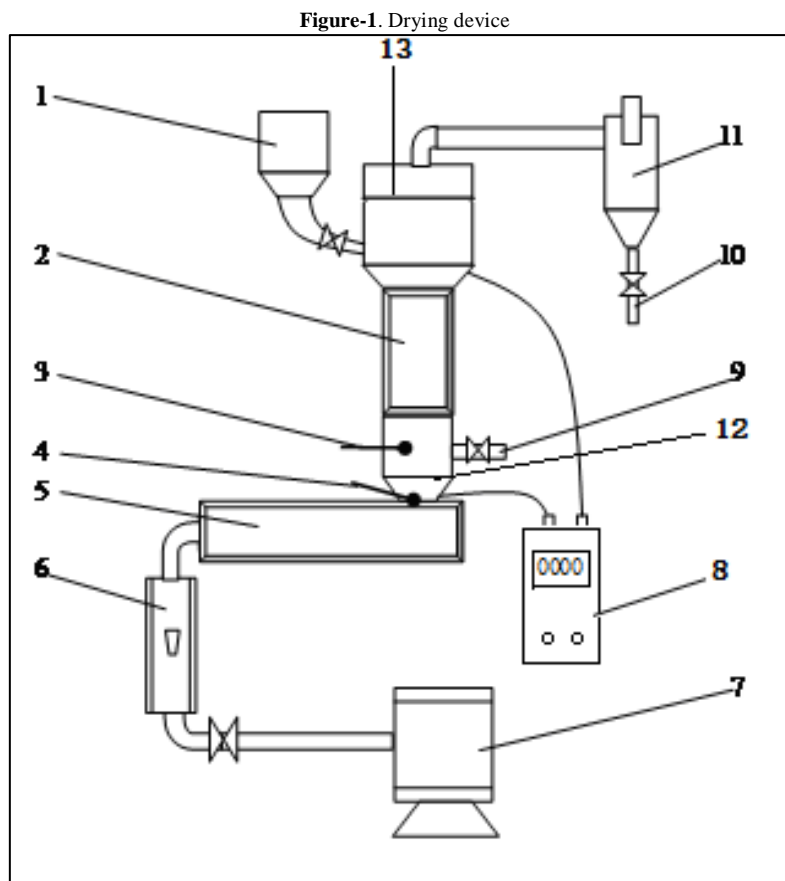
Higher education should cultivate students' innovation and entrepreneurship, and take "practical teaching" as a key link in deepening teaching reform [1]. Experiment teaching is an effective way to carry out comprehensive chemical education [2-5]. However, the teaching contents of traditional experimental teaching still remain at the verification or strength of theoretical knowledge [6]. Therefore, there are a series of problems such as experimental content "standardization", experimental implementation "instillation" and experimental report "formatting". Even if students do not understand the experimental principle, they can still "follow the instruction" and "successfully" complete the experiment. However, this "standardized" teaching mode is difficult to provide students with space and time for thinking and practice, and it is not able to stimulate their interest in active participation. This seriously restricts the formation and improvement of practical ability and innovative consciousness. Therefore, deepening the reform of experimental teaching content, providing them with innovative experimental platform and scientific guidance is the most important.

Research exploratory experiments can help students reveal scientific principles and discover scientific laws by simulating the process of "exploration and discovery" [7, 8]. In order to improve comprehensive ability, instructors must pay more attention to the design and research-based experiments, which can train students to discover problems, analyze problems and solve problems. Drying is a typical chemical engineering unit operation, which integrates laws of fluid flow and transfer, heat transfer and mass transfer. Fluidized bed drying is an important experimental project in chemical engineering experiments. In the fluidized state, heat transfer and mass transfer between wet materials and hot air carry out. In traditional experiment, either students conduct the fluidized bed drying at the specified flow rate [9]; or the fluidization curve measurement and the fluidize drying are set up independently [10]. The independent project is basic, verifiable, and the content is lack of coherence and scientific. In order to convert the experiment into design and research type, and also compare it with the well-known fixed bed (oven) drying, the research integrates three independent basic experiments into an organic whole by improving the experimental device, screening the drying materials and integrating the fluidization curve measurement, fixed bed drying and fluidized bed drying. In addition, through heuristic teaching, students are guided to complete the experiment design, implementation, comparison and analysis of fluidized curve measurement, fixed bed drying and fluidized bed drying. The construction and application of the project play an important role in improving students' comprehensive quality.

## 2. Construction of Fixed Bed, Fluidized Bed and Fluidized Drying Experiment System

### 2.1. Improvements on the Instrument

Fluidization curve, fixed bed drying and fluidized bed drying experiments involve the measurement of pressure difference produced by air flowing through particle bed. The original equipment was equipped with a U-type differential pressure gauge with water as indicator [11, 12]. However, it's difficult to ensure the rapid and accurate reading of instantaneous data due to the large fluctuation in the actual experiment. At the same time, the measuring range of U-type differential pressure gauge is far beyond the bed pressure difference, which leads to the high absolute errors and relative errors. Based on the experimental content and material needs, it was replaced by a direct reading digital pressure gauge with a resolution ratio of 1 Pa (see Figure 1). Compared with the original equipment, the absolute error and relative error are reduced by 10% and 5%, respectively.



1. loading hopper, 2. particulate bed (visible), 3. temperature measuring point inside the bed, 4. temperature measuring point out of heater, 5. air pre-heater, 6. rotor flow meter, 7. air blower, 8. digital differential manometer, 9. sample connection, 10. ash hole, 11. cyclone separator, 12. distributor, 13. filter net

### 2.2. Selection of Experimental Materials

The fluidized drying material provided by the manufacturers is mung beans with a size of about 3 mm. In order to ensure the consistency of the experimental contents and accuracy of the results, the media used in the fixed bed, fluidized bed and fluidized drying experiments should be unified. Furthermore, the particle size cannot be affected by soaking. For this purpose, spherical molecular sieves with diameters of 1.6~2.5 mm, 2.0~4.0 mm, 3.0~5.0 mm and 4.0~6.0 mm were respectively tried as experimental material, and fluidized curve, fixed bed drying, fluidized bed drying experiments were carried out successively. Finally, molecular sieve with a size of 1.6~2.5 mm was selected as the experimental material. It cannot only ensure the fluidized curve, fixed bed drying and fluidized bed drying experiment, but also ensure the accuracy of the results. The specifications of molecular sieve were shown in Table 1, and the poriness was calculated according to equation (1).

$$\varepsilon = \frac{\rho_s - \rho_b}{\rho_s} \quad (1)$$

**Table-1.** Properties of molecular sieves

Material	Shape	Size $d_p$ /(mm)	Density $\rho_s$ /(kg/m <sup>3</sup> )	Packing density $\rho_b$ /(kg/m <sup>3</sup> )	Poriness $\varepsilon$ /(%)
Molecular sieves	Sphere	1.6~2.5	1689	777	0.540

## 2.3. Experimental Scheme

To provide sufficient basis for experiment design and its implementation, students were firstly guided to carry out the fluidization curve measurement in order to understand the characteristics and difference between fixed bed and fluidized bed, and then provided air flow data for the subsequent drying experiments. After that, students were advised to try drying firstly under fixed bed conditions and then carry out the fluidized bed drying. The above approach can make students deeply master the key factors to control different drying states, and understand the advantages of fluidized bed drying. The specific experimental scheme is as follows:

### 2.3.1. Determination of Fluidization Curve

Molecular sieve particle sized 1.5~2.6 mm is taken as test objects. Fluidization curve is drawn by measuring the air flow rate and the corresponding reduced pressure ( $\Delta P$ ) of the particle bed. The critical fluidization velocity ( $u_{mf}$ ), the corresponding air flow rate ( $q_v$ ) obtains from the curve of the air tower velocity ( $u_0$ ) to  $\Delta P$ . Specific methods: changes the value of  $q_v$  in the maximum flow range and detects the corresponding  $\Delta P$ . Using  $q_v$  and bed diameter ( $d$ ),  $u_0$  is calculated according to equation (2). The fluidization curve of molecular sieve is obtained by drawing of  $\Delta P$  to  $u_0$ . The  $u_{mf}$  of and the corresponding  $q_v$  are obtained.

$$u_0 = \sqrt{\frac{4q_v}{\pi d^2}} \quad (2)$$

### 2.3.2. Drying Experiment in a Fixed Bed

Keep wet molecular sieve (after soaking and absorbing water) in a fixed bed state, the  $\Delta P$  and the bed temperature ( $T_0$ ) are measured as a function of drying time ( $\tau$ ) under a constant drying conditions. Then draw the drying curve and drying rate curve respectively. Specific methods: Referring to the fluidization curve, selecting and controlling a  $q_v$  that maintains the molecular sieve in a fixed bed state. Preheat the air, raise the temperature and keep the inlet temperature constant ( $T_i$ ) as a constant, the wet molecular sieve are then added, the changes of  $\Delta P$  and  $T_0$  with  $\tau$  are recorded until the  $\Delta P$  keeps a constant. Then calculates the dry basis moisture content ( $X_i$ ) according to equation (3) by using  $\Delta P$  of different times and  $\Delta P$  of equilibrium state (labeled as  $\Delta P_e$ ). Dry curve can be drawn using the  $X_i$  and  $\tau$  data. Take points from the  $X_i \sim \tau$  curve and find the slope of the taken point to obtain several groups of  $(-dX/d\tau)$ . During the drying, heat transfer area ( $S$ ) and the absolute dry material quality ( $G_c$ ) are constant, so the drying speed ( $U$ ) represented by the equation (4) can be replaced by  $-dX/d\tau$ . Plot with  $-dX/d\tau$  to  $X_i$  obtains the drying speed curve.

$$X_i = \frac{\Delta p_i - \Delta p_e}{\Delta p_e} \quad (3)$$

$$U = -\frac{G_c}{S} \cdot \frac{dX}{d\tau} \quad (4)$$

### 2.3.3. Drying Experiment in a Fluidized Bed

Keep the wet particles in a fluidized bed state, measure  $\Delta P$ ,  $T_0$  and  $\tau$  under a constant drying conditions. Then draw the drying curve and drying rate curve respectively. Specific methods: Referring to the fluidization curve, selecting and controlling a  $q_v$  that maintains the particles in a fluidized bed state. Preheat the air, raise and then keep the  $T_i$  as a constant, the wet particles are then added, changes of  $\Delta P$  and  $T_0$  with  $\tau$  are recorded until the  $\Delta P_i$  keeps a constant. Then calculate the  $X_i$  according to equation (3) by using  $\Delta P_i$  and  $\Delta P_e$ . Draw dry curve with  $X_i$  and  $\tau$ . Take the point from the  $X_i \sim \tau$  curve and find several groups of  $-dX/d\tau$ . Plot with  $-dX/d\tau$  to  $X_i$  and obtain the drying speed curve.

## 3. Application of Fixed Bed, Fluidized Bed and Fluidization Drying Comprehensive Experiment

Some raw data and experimental results are as follows.

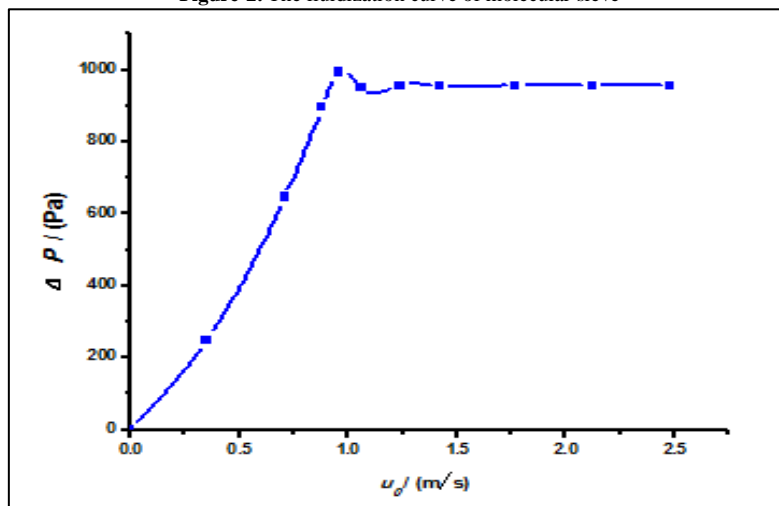
### 3.1. Determination of Fluidization Curve

About 1000 mL particles are added to the dryer to determine the corresponding  $\Delta P$  under different  $q_v$  and  $u_0$ , and the results are listed in Table 2. The fluidization curve is obtained by plotting  $\Delta P$  versus  $u_0$ . As can be seen from Figure 2,  $u_{mf}$  and its corresponding  $q_v$  are read as 1.25 m/s and 35.3 m<sup>3</sup>/h, respectively.

Table-2. Data in fluidization experiment

$q_v$ /(m <sup>3</sup> /h)	0	10	20	25	27	30	35	40	50	60	70
$u_0$ /(m/s)	0	0.35	0.71	0.88	0.96	1.06	1.24	1.42	1.77	2.12	2.48
$\Delta P$ /(Pa)	0	248	647	895	994	952	956	955	957	957	956

Figure-2. The fluidization curve of molecular sieve



### 3.2. Determination of Drying Curve of Fixed Bed Dryer

Under the constant drying condition of  $q_v$  25 m<sup>3</sup>/h and air  $T_i$  67 °C, about 1000 mL wet molecular sieves are added to the dryer, and the particles present as a fixed bed. Recorded the changes of  $\Delta P_i$  and  $T_o$  with  $\tau$ , and the results are listed in the Table 3. Based on the data and equation (3), the  $X$  corresponding to  $\tau$  and the drying curve shown in Figure 3 is obtained. Since  $S$  and  $G_c$  are constants in the experiment, the  $U$  is proportional to  $(-dX/d\tau)$ . Using the  $X \sim \tau$  data or the first derivative of the  $X \sim \tau$  curve, the  $U \sim X$  drying speed curve shown in Figure 4 is drawn. The critical moisture content  $X_C$  (0.204 kg/kg) and equilibrium moisture content  $X_D$  (approx. 0 kg/kg) are further obtained.

Table-3. The fixed bed dryer data

$\tau$ /(min)	0	0.5	1	2	3	5	7	9	13	20	30	40	50	60
$\Delta P$ /(Pa)	1001	966	950	948	928	874	833	811	770	750	734	696	693	692
$T_o$ /(°C)	24	24	24	24	26	26	30	36	56	64	66	66	66	66

Figure-3. Drying curve in fixed bed dryer

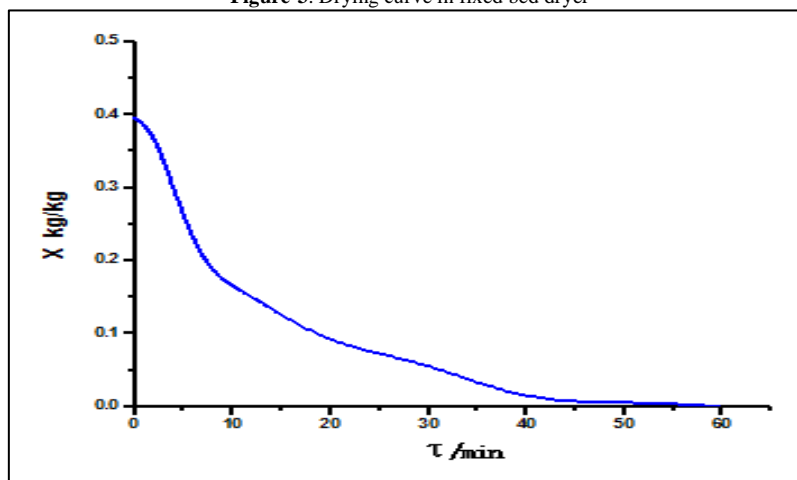
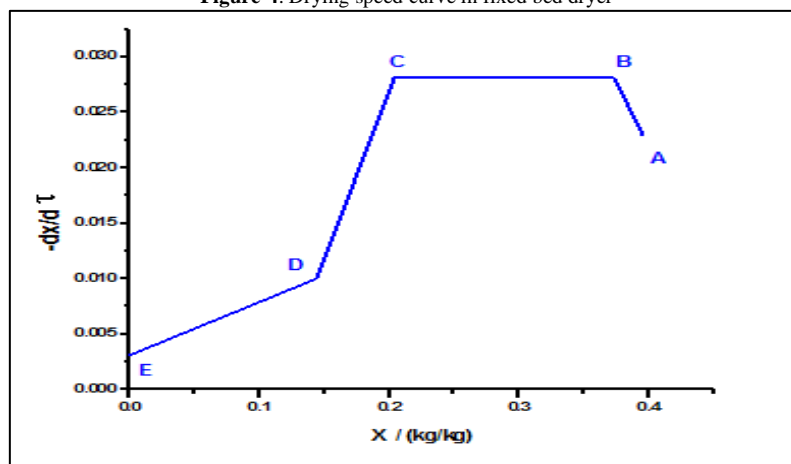


Figure-4. Drying speed curve in fixed bed dryer



### 3.3. Determination of Drying Curve of Fluidized Bed Dryer

According to the fluidization curve of molecular sieve, air flow rate of  $60 \text{ m}^3/\text{h}$  higher than  $u_{mf}$  and  $T_i$   $67^\circ\text{C}$  are selected, about 1000 mL wet molecular sieves are added, and the particles appear as a fluidized bed. Record the changes of  $\Delta P_i$  and  $T_o$  with  $\tau$ , and the results are listed in the Table 4. Based on the data and equation (3), the  $X$  corresponding to  $\tau$  and the drying curve shown in Figure 5 is obtained.  $S$  and  $G_c$  are constants in the experiment, so the  $U$  is proportional to  $(-dX/d\tau)$ . Using the  $X \sim \tau$  data or the first derivative of the  $X \sim \tau$  curve, the  $U \sim X$  drying speed curve shown in Figure 6 is drawn. The critical moisture content  $X_c$  ( $0.05978 \text{ kg/kg}$ ) and equilibrium moisture content  $X_D$  (approx.  $0 \text{ kg/kg}$ ) are further obtained.

Table-4. The fluidized bed dryer data

$\tau/(\text{min})$	0	1	3	4	6	9	12	13	14	17	19
$\Delta P/(\text{Pa})$	916	913	906	896	853	851	844	805	804	803	803
$T_i/(\text{C}^\circ)$	34	36	36	36	36	41	52	55	55	59	60

Figure-5. Drying curve in fluidized bed dryer

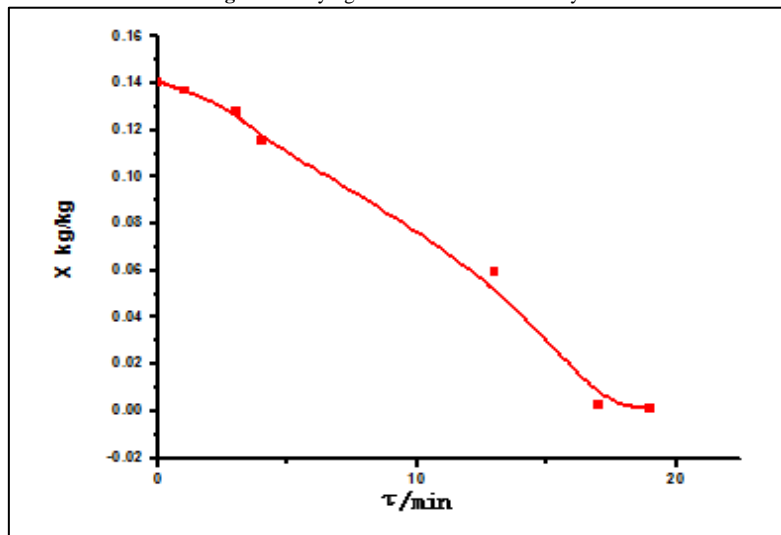
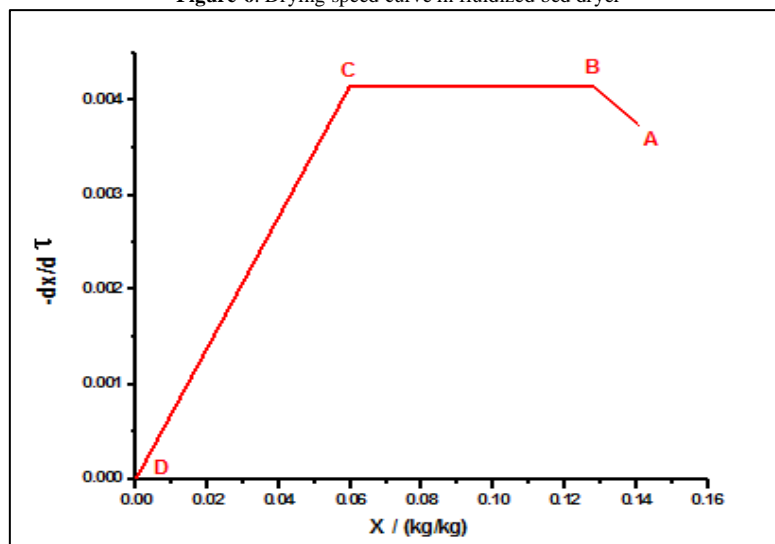


Figure-6. Drying speed curve in fluidized bed dryer



## 4. Experiment Effect

The orderly implementation of comprehensive experiment of fluidized, fixed bed drying and fluidized bed drying has increased the designability and scientificity. It plays important roles in cultivating students' ability of experimental design, research and innovation. Through implementation of the experiment, the students can observe the difference between the fixed bed dryer and the fluidized bed dryer, and can also grasp the key factors of the selection and setting of the experimental conditions. In particular, students realize that compared to fixed beds, fluidized bed has: each particle has larger heat transfer area and mass transfer area (particles are suspended and dispersed in the air phase in fluidized state); the heat transfer driving force and mass transfer driving force are consistent, and the particles are evenly dried (the characteristics of fluidization); good drying quality and drying speed (reflected by  $U$ ); high efficiency (reflected by  $\tau$ ); high heat utilization rate (reflected by  $T_o$ ); high air flow and power consumption; high mechanical wear and damage to the particles.

## 5. Conclusion

Breaking the traditional teaching mode, the optimization and integration of fluidization, fixed bed drying and fluidized bed drying into a design-based and research-based project can enable students to fully master the experimental purpose, principle, instrument function, condition setting and operation, data processing and result analysis. Students change from imitative and passive learning to autonomous and research-based learning. It improves the ability of analyzing and solving problems, and improves student ability of innovative thinking and practice.

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