

Methods for Improvement of the Thermal Efficiency during Spray Drying

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Abstract. Spray drying is a kind of unit operation with high energy consumption and relatively low energy utilization, and the problem of low thermal efficiency has been attracted the attention by scholars at home and abroad. The factors affecting the thermal efficiency of spray dryer are analyzed. From a technical point of view, the thermal efficiency of spray dryer can be increased through the unit operation. Measurements for the reduction of energy saving of spray dryer were put forward.

1 Introduction

Spray drying is one of the types of drying technology, which is suitable for processing the solutions, suspensions and slurry-like materials. According to the way of liquid atomization, the atomizer is divided into three types: pressure type, centrifugal type and air flow type. The feeding liquid can become fog droplet with micron order, then they are rapidly dried into particles with a diameter about 30~500 μm by hot air within 5~30s. Spray drying has been widely used in chemical industry, biological and food processing, pharmaceutical manufacture and other fields due to its continuous and automatic operation, instant dry, low labour intensity and good working environment. However, spray drying is a kind of unit operation with high energy consumption and relatively low energy utilization. The hot air is used as the drying medium in spray dryer. It was reported that the heat efficiency of spray dryer is about 25% to 60%, and some even are below 20%^[1]. The above results show that the heat consumption of spray drying is a large cost, generally speaking, the heat consumption accounts for 60% of the total cost. According to recent studies, about 42% energy of hot air cannot be used^[2], showing that energy waste is astonishing. The energy saving problem of spray dryer has been attracted the attention by scholars at home and abroad. However, how to increase the thermal efficiency has been lack of systematic research. The present study summarizes the advanced methods for energy saving of spray dryer, which can give reference for the technical transformation of spray drying industry.

2 Analysis of spray drying efficiency and effect factors

Thermal efficiency of spray drying η can be approximately expressed as below^[3]:

$$\eta = (T_1 - T_2) / (T_1 - T_0) \times 100\% \quad (1)$$

where: the η in this equation is the thermal efficiency, %; T_1 is the inlet hot air temperature of spray dryer, $^{\circ}\text{C}$; T_2 is the outlet air temperature of spray drying atomizer, $^{\circ}\text{C}$; T_0 is the environmental temperature, $^{\circ}\text{C}$.

In order to express the use of heat energy in spray drying process directly, the thermal efficiency can be expressed in another form^[4]:

$$\frac{(\text{Heat of materials heating} + \text{Heat of water evaporation})}{\text{Heat input}} \times 100\% \quad (2)$$

The formula (2) shows that the main factors affecting the thermal efficiency are the solid content and temperature of feeding materials, the inlet and outlet temperature of spray dryer. In order to solve the problem of energy saving in the spray drying process, the researchers should pay more attention to the thermal efficiency, which is the core issue.

3 The measures for the reduction of energy consumption of spray dryer

According to domestic and foreign research experience, there are several measures for the reduction of energy consumption in spray drying process.

3.1 Increasing the feeding concentration

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As far as the drying process is concerned, the water evaporation per hour is a constant value. The higher the feeding solid content, the lower is the energy consumption of unit weight product. It was reported that the drying efficiency will increase 6% if the feeding solid content increases from 20%(w/w) to 21%(w/w)^[5]. However, there is a contradictory relationship between the feeding solid content and fluidity. On the one hand, the fluidity of feeding fluid becomes inferior with a higher feeding solid content, leading to a poor atomization; on the other hand, the fluidity of feeding fluid becomes better with a higher water content, leading to a high evaporated load.

From the point of view of energy saving, both of the fluidity and solid content of feeding fluid should be higher. In order to solve this problem, some electrolytes can be added into the feeding fluid, and this method has achieved better results^[6].

3.2 Selecting the suitable atomizer

For the same materials, the viscosity of fluid increases with the increased solid content. Liu^[1] reported that the flowing resistances of the suspension of chrome is 10,000 times higher than water at the flowing rate of

0.2~0.3 meter per second. It is almost impossible to atomize this kind of fluid at such high resistance by pressure or rotary atomizer. In contrast, the pneumatic atomizer is suitable for atomizing the high viscosity fluid. Nevertheless, the economic cost for the pneumatic atomizer is higher than the pressure or rotary atomizer. Therefore, the principle of electing atomizer is given as follows. Firstly, the pressure atomizer or rotary atomizer are preferred; secondly, the feeding solid content should be higher properly; thirdly, the pneumatic atomizer can be used when the feeding fluid is difficult to atomize.

3.3 Increasing the feeding temperature

When the temperature of feeding liquid increases, the viscosity of fluid would decrease, as a results of good atomizing performance. Studies have shown that if the temperature of feeding fluid increased from 30°C to 70°C, the drying efficiency would increase from 71.9% to 79.8% (Table 1).

Of course, the feeding temperature cannot be increased indefinitely. For thermal sensitive materials, the temperature of feeding liquid cannot exceed the critical value which the thermal sensitive materials are destroyed.

Table 1. Effect of feeding temperature on thermal efficiency

Feeding temperature (°C)	Thermal efficiency (%)
30	71.9
40	74.3
50	76.5
60	78.3
70	79.8

Table 2. Effect of the inlet air temperature on the drying efficiency

Inlet air temperature (°C)	Thermal efficiency (%)
150	60.4
250	74.1
350	80.0
450	83.5
550	85.8

Table 3. Effect of outlet air temperature on the thermal efficiency

Outlet air temperature (°C)	Thermal efficiency (%)
80.4	76.8
90.4	72.2
95.2	70.0
100.1	67.7
105.3	65.5

3.4 Increasing the inlet air temperature of spray dryer

The increase of the inlet air temperature is beneficial to increase the thermal efficiency of spray dryer (Table 2), but this method is limited by the nature of the product,

especially in counter-current operation process. In the confluence operation process, however, the inlet air temperature is permitted to much higher than the denatured temperature of products.

3.5 Reducing the outlet air temperature of spray dryer

In the energy supplied by the preheater, about 20%~40% of the total heat is taken away by the exhaust gas, and some even as high as 60%. If the temperature of the outlet air can be minimized, the heat efficiency of the spray dryer can be increased (Table 3).

In comparison, it is more economical to lower the outlet air temperature than to increase the inlet air temperature. Nevertheless, the outlet air temperature is limited by two factors: one is the required moisture content, the other is the temperature must be higher 20~50°C than the dew point of waste gas.

3.6 Recovery of waste heat

Obviously, the recovery of waste heat from the spray dryer is very important. The heat loss from the spray dryer is mainly achieved through three factors. Firstly, the heat can be taken away by the drying products, which is about 1.5% of total heat. Secondly, the heat is transferred through the wall of spray dryer, which is about 7.5% of total heat. Thirdly, the heat can be taken away by the exhaust gas, which is about 34% of total heat. It can be seen from the above analysis, the main source of energy loss is the emission of waste gas. Therefore, the recovery of waste gas is an important way for energy saving. In recent years, the application of heat pipe technology has brought greater hope to the recovery of this part of residual heat from spray dryer.

There was a view in the past that it has no economic value for the recovery of waste gas with the temperature below 100°C^[5]. With the development of technology as well as the usage of tubular heat exchanger, the heat from waste gas with low temperature can also be recycled. Compared to the traditional heat exchanger, the tubular heat exchanger has the following characteristics. Firstly, the heat transfer coefficient is high. Secondly, the thermal resistance is low. Therefore, it is a relatively proper method to recover the waste heat by tubular heat exchanger. Besides, the technology of heat pumps is also a reasonable method for recovery of waste heat.

4 Conclusion

Spray drying is a kind of unit operation with high energy consumption and relatively low energy utilization, therefore, the problem of energy saving has been attracted the attention by the scholars at home and abroad. The thermal efficiency of spray dryer can be increased through the unit operation. For the feeding liquid, the higher solid content and temperature of feeding liquid is benefit to increase the thermal efficiency; for the heating system, the higher inlet air temperature and lower outlet air temperature is benefit to increase the thermal efficiency. In addition, the suitable atomizer and waste heat recovery are important ways for the increase of thermal efficiency.

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