Development and Application of Moisture Control System with IR Moisture Sensor to Aqueous Polymeric Coating Process

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A new practical method of controlling the moisture content of particles in an aqueous polymeric coating by a tumbling fluidized bed is described. The method was based on the on-line measurement and feedback control of moisture content by use of an IR (infrared) moisture sensor. Spherical core particles made of crystalline cellulose were coated in the tumbling fluidized bed by atomizing the suspension of enteric acrylic copolymer (Eudragit L30D-55). The influence of moisture control, conducted with two different methods (PID (proportional-integral-derivative) control and on-off control), on the drug release rate and on the agglomeration tendency of coated particles was investigated. It was found that moisture control by the PID control method was useful for producing the desired coated particles which exhibited excellent properties in delayed release with a low agglomeration tendency.

Keywords aqueous polymeric coating; moisture control; IR moisture sensor; tumbling fluidized bed; delayed release; agglomeration tendency

Introduction

Film coatings for oral drugs with polymeric substances are the method used for controlling the release rate of active materials. The aqueous dispersion of synthetic polymers has recently been widely used in place of the organic solvent system because of environmental and economic advantages. In using aqueous polymers to film coating without any consideration of drying efficiency of the equipment, undesirable results such as the adhesion of particles occurs owing to the formation of a liquid bridge by the slow speed of water evaporation at the surface of the core particles.[1]

As for the coating efficiency in the fluidized bed coating operated by atomizing the suspension of inorganic fine particles, Kage *et al.*[2] have pointed out that when the moisture content was kept high, high coating efficiency was obtained. E. Abe *et al.*[3-6] also described that the coating efficiency was explained by use of the moisture content measured indirectly.

Therefore, moisture content is the main factor in the aqueous coating process regardless of the film materials, however, there is no report which describes any device to measure the moisture content continuously nor any practical method to control it.

The purpose of this contribution is to establish a system of controlling the moisture content by use of an IR moisture sensor[7-9] and to investigate the importance of moisture control in the aqueous coating process by the tumbling fluidized bed. The instructions for producing coated particles which have excellent properties in delayed drug release without agglomeration will also be suggested on the basis of moisture control.

Experimental

Powder Samples Figure 1 shows the scanning electron microscopic (SEM) photograph of a core particle used. As the core particles, spherical granules made of crystalline cellulose (Celphere CP507, Asahi Chemical Industry Co., Ltd.), of which the mean particle diameter, measured by a rowtap method, was 600 μm and true density was 1.07 g/cm^3 were used. Dispersion of entersoluble, acrylic polymer (Eudragit L30D-55, Rohm Pharma) which was resistant to gastric juice but soluble in intestinal juice with a solubility around and above pH 6 was adopted as the coating material. Dispersion of the Eudragit L30D-55 in this study was diluted with water to contain 15% of solid acrylic copolymer. Triethyl citrate was added as a plasticizer (15% weight of copolymer) before application.

Equipment Figure 2 illustrates the experimental set-up of the aqueous coating system. The tumbling fluidized bed[7,8] (NQ-LABO, Fuji Paudal Co., Ltd.) was used for the coating operation. At the bottom of the coating chamber an agitator blade was equipped with a slit plate attached below. Owing to the rotation motion of the agitator blade, adhesion of particles was prevented and polymer particles sprayed on the surface of the core were spread to make a smooth and continuous film. The drying efficiency was also promoted by the heated fluidization air blown through the slit. Here we applied the side spray method while we used the top spray method in the wet granulation process[7,8] reported previously. Since the top of the spray gun in the side spray method was in contact with the powder bed, the adhesion of coated wet particles to the top of the spray gun and the spray-drying of spray mist were prevented if we applied the side spray method. The tangential spray method was impossible to use because the diameter of the coating chamber was so small that the particle flow was made turbulent and the dispersion of the spray mist was not uniform.

Continuous measurement of the moisture content during the operation was carried out by means of the IR moisture sensor[7,8] (WETEYE, Fuji Paudal Co., Ltd.). The moisture feedback control in this study was conducted by two different methods; PID (proportional-integral-

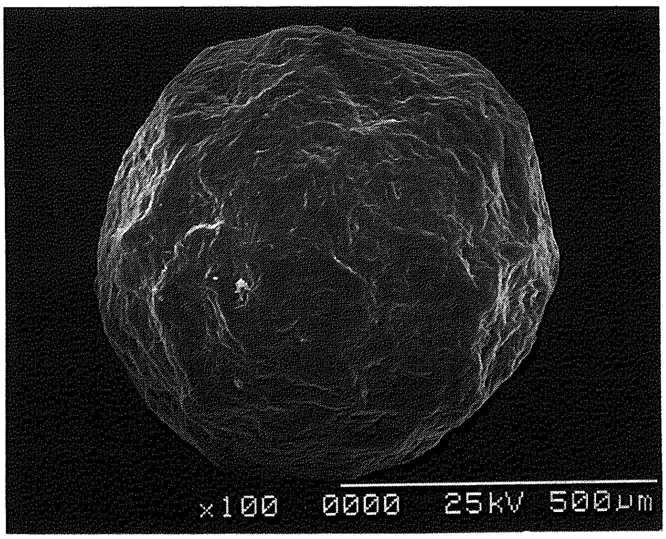

Fig. 1. Scanning Electron Microscopic Photograph of a Core Particle

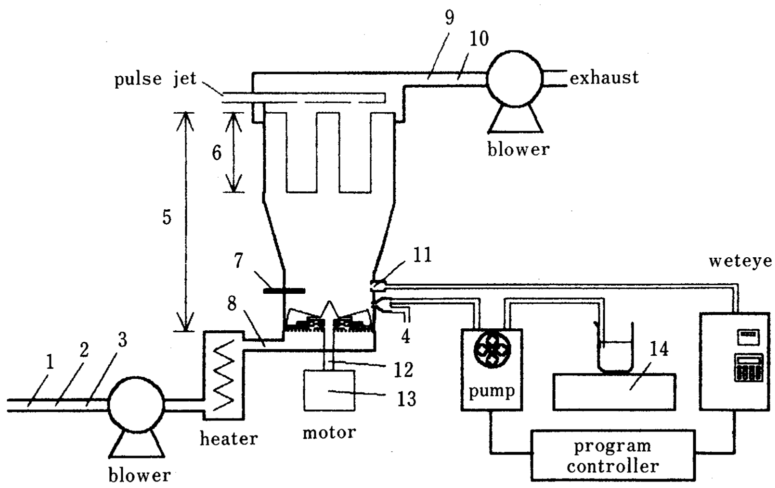

Fig. 2. Experimental Set-up of Aqueous Coating System

1, air flow rate; 2, inlet air humidity; 3, inlet air temperature; 4, spray air flow rate; 5, inside pressure; 6, bag differential pressure; 7, object temperature; 8, temperature of heated air; 9, outlet air humidity; 10, outlet air temperature; 11, moisture content; 12, agitator rotation speed; 13, power consumption; 14, amount of dispersion sprayed.

TABLE I. Experimental Conditions

Inlet air velocity	1.0 m/s
Heated air temperature	35 °C
Spray pressure	1.5×10^5 Pa
Agitator rotation speed	300 rpm

derivative) control and on-off control.

Other operational factors such as the agitator rotation speed, air flow rate, bed inside pressure, and inlet air temperature were feedback controlled (PID control) to maintain stable operation. In addition, the temperature of product and outlet air, the humidity of inlet and outlet air, the differential pressure of bag filter, and the weight of dispersion sprayed were also measured.

Output signals from each sensor were all translated and digitalized in a 12 bit A/D converter in a personal computer. During the experiment, these measuring data were all monitored, and after that, memorized in floppy disks.

Methods Experimental conditions used are listed in Table I. The core particles of 300 g were first undercoated with a water-solution of pigment (Blue No. 1, Toushoku Pigment Co., Ltd.) selected as an active substance. After drying these particles in this coater, the dispersion of Eudragit L30D-55 was sprayed under moisture control. After having sprayed 300 g of the dispersion, coated particles were dried in the coating chamber until the moisture content decreased to under 1 wt%.

Evaluation of the Coated Particles The condition of the film formed was evaluated by the dissolution tests by use of a UV-visible recording spectrophotometer (UV-160A, Shimadzu Co., Ltd.). In this system, concentration of the released pigment which was undercoated onto the core particles was measured in accordance with the JP XI paddle method[10] at 100 rpm and 37 °C. Here, the dissolution medium was 0.05 M phosphate buffer (pH = 7.2, 900 ml), and the sample was 0.5 g of the coated particles.

Results and Discussion

Relation between Moisture Content and the Absorbance of IR Rays Before applying the IR moisture sensor to the aqueous coating process, we will briefly describe the fundamentals of the structure and the measuring principles of the sensor. Water has absorption peaks at wave lengths of 1.43, 1.94 and 3.0 μm. When the infrared spectrums at these absorption peaks are irradiated to a wetting substance, energy of the spectrums are absorbed in proportion to their moisture content. Based on this principle, the moisture content of a substance can be calculated by the ratio of the energy of the flood to that of the reflected. The IR moisture sensor has advantages in that it can measure the moisture content continuously without touching the object, while it can detect only the surface water because of the optical properties. If the object has a moisture concentration gradient between the surface and the inside, the moisture content can be measured on the assumption that the output from the sensor has a linear correlation to the average moisture content measured by the drying method and the like. Therefore, we investigated the correlations which are thought to be necessary if we apply the IR moisture sensor to the aqueous coating process.

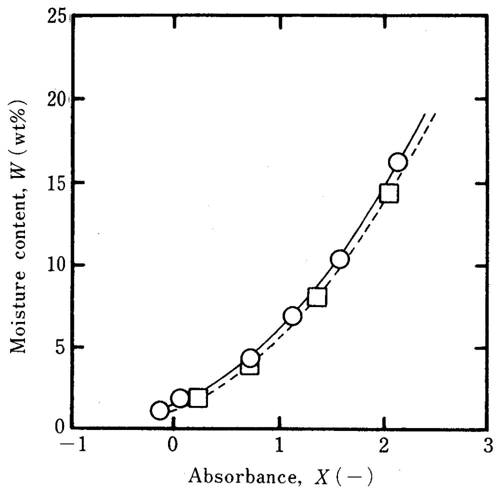

Fig. 3. The Plots of Moisture Content as a Function of Absorbance of IR Rays

○, dampening process; □, drying process.

Figure 3 shows the plots of moisture content as a function of the absorbance of the IR rays (wavelength used was 1.94 μm) when we dampen the core particles (Celphere CP507) by spraying water and remove the water by drying. Here, the moisture content by use of the drying method was measured by substituting the wet mass (M_w) of the particles sampled out during the operation and

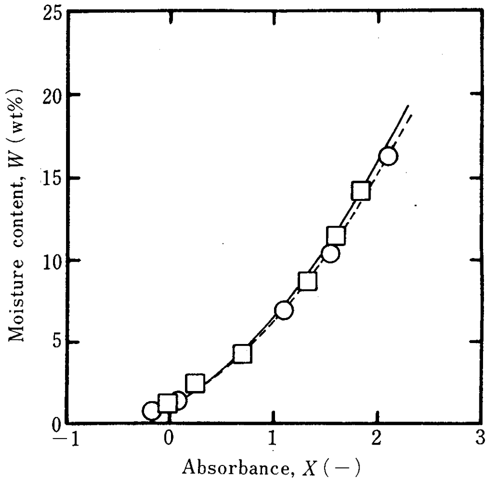

Fig. 4. The Plots of Moisture Content as a Function of Absorbance of IR Rays

○, water; □, Eudragit L30D-55.

their dry mass (M_d) obtained after drying for 24 h at 50 °C on a shelf dryer to the following equation.

$$\text{moisture content, } W\ (\text{wt\%}) = \frac{M_w(\text{g}) - M_d(\text{g})}{M_w(\text{g})} \times 100$$

There is no significant difference between the plots of the dampening process and the drying process in Fig. 3, but the drying process indicates a slightly larger absorbance than the dampening process, if compared at the same moisture content. This fact implies that the moisture distribution gradients in the core particles are almost the same in both the dampening and drying processes. In the case of the drying process, however, since the water moves from a deeper place to the surface by a thermal driving force, the amount of water existing near the surface where the energy of the IR rays are absorbed is larger than that of the dampening process, even if the particles have the same moisture content. Therefore, it is recognized that the drying process shows a little larger absorbance than the dampening process, if compared at the same moisture content.

Figure 4 also illustrates the plots of moisture content as a function of absorbance of IR rays in the case of spraying water and spraying the dispersion of Eudragit L30D-55. The plots of water and Eudragit L30D-55 are in close agreement in the low moisture content range, however, a slight difference arises in the high moisture content range. As the coating progressed, roughness disappeared on the surface of the core and the reflection factor changed because the surface of the core was covered with polymer film. When the film was formed, since the water added by spraying diffused through the polymer film with a strong penetration resistance, water absorbing power became poorer and the moisture distribution gradient between the surface and the inside of the particles also changed. It is suggested that these are the reasons why the absorbance of the IR rays of the coated particle in Fig. 4 shows a smaller value than that of the non-coated one if compared at the same moisture content.

Viewing the coating phenomena microscopically, the coating process is a repeat of spraying and drying at a moment, thus, in order to measure the moisture content

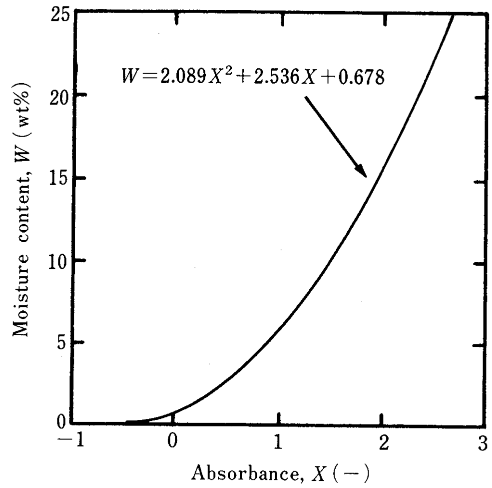

Fig. 5. The Hypothetical Relation between Moisture Content and the Absorbance of IR Rays by Use of the Least Square Method

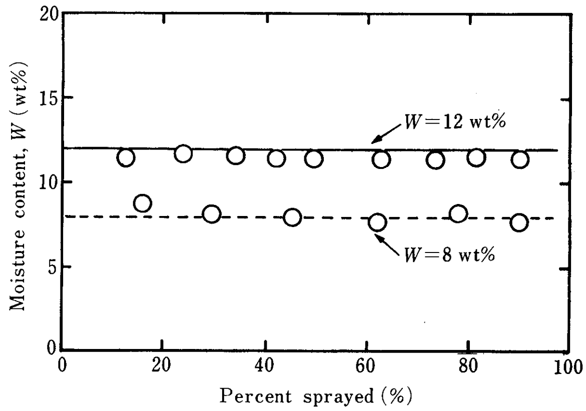

Fig. 6. The Plots of Moisture Content as a Function of the Ratio of the Amount Sprayed to the Total Spray Liquid

○, moisture content calculated by drying method; solid and dotted lines, moisture content by IR sensor.

accurately we must take both spraying and drying processes into account in the relation between the moisture content and the absorbance of the IR rays. Thus, we proposed the hypothetical function as shown in Fig. 5 by use of the least square method to the relation obtained in Figs. 3 and 4. The function is estimated as follows;

$$W\ (\text{wt\%}) = 2.098X^2 + 2.536X + 0.678$$

(X: absorbance of IR rays, W: moisture content)

In order to verify the possibility of measurement, accuracy of measurement was experimentally investigated.

Figure 6 illustrates the moisture content as a function of the amount of spray liquid under moisture control at two references ($W = 8$ wt%, 12 wt%). The plots are the moisture content calculated by the drying method (W_d), and the solid and dotted lines are the moisture content measured by the IR moisture sensor (W_m). The fact that the accuracy of measurement has no difference as the increase of the amount of spray liquid, describes that the hypothetical function illustrated in Fig. 5 can measure the moisture content with high accuracy. It was found from the results that accuracy of the measurements, defined as $(W_m - W_d)/W_d \times 100$, were better than $\pm 0.5\%$ (W_m; moisture content measured by IR sensor, W_d; moisture content measured by drying method).

Influence of the Moisture Control on the Properties of Coated Particles PID control and on-off control are widely used as a method of feedback control. In order to control the moisture content by feedback control, it is necessary to inverstigate the influence of the moisture control by each method on the properties of coated particles and to select the appropriate one. A detailed comparison of the two control methods when applied to the moisture control in the aqueous coating process will be made below in terms of the dissolution test and agglomeration tendency, and in addition the results of the coating in the case of the no-control experiment will be presented.

Here, PID control is conducted by controlling rotation speed of the pump by use of a digital program controller, while on-off control is performed by on-off switching of the electric supply of the pump by the pulse signal from the IR moisture sensor. In this study, the set-point value of the operational moisture content was selected to be 12 wt% in accordance with the pre-experimental results.[11] In the dampening process ($0 \leqq t \leqq 12$ min), purified water was sprayed until the moisture content reached the set-point value ($W = 12$ wt%). After having sprayed the 300 g of dispersion, the drying process (near at $t = 60$ min) was started.

Temporal changes of the moisture content by the PID, on-off control method and the no-control experiments conducted by spraying at a constant feed rate are illustrated in Figs. 7, 8 and 9, respectively. Comparing the two control methods, controlled deviation in the PID control was smaller than that of the on-off control. Since the dead time element in this system is largely due to the slow speed of water penetration through the polymer films, it cannot avoid overshoot in the on-off control method. Thus, the PID control where controlled variables are determined by the controlled deviation, easily maintains stability in this aqueous system.

In Fig. 9, coating was conducted without controlling the moisture content, while Eudragit was continuously sprayed at the two constant feed rates (3.7 and 7.4 g/min). Here, 7.4 g/min was the speed selected to spend the same time which was needed to spray 300 g of dispersion in the PID moisture control experiment (Fig. 7). In both cases the moisture content increased slowly and fluctuation of the moisture content was small.

Although the dynamic characteristics of the control in each method was made clear, the effect of each method on the properties of the coated particles remains unknown, thus, we will investigate the release rate by dissolution tests and the agglomeration tendency of the coated particles by use of particle size distribution.

The results of the dissolution tests of each method are shown in Fig. 10. The release rates become slower in the order of no-control at 7.4 g/min, no-control at 3.7 g/min, on-off moisture control, and PID moisture control.

Among the four methods, products made by the no-control method show a remarkably fast release rate. As K. Lehmann *et al.*[1] have already pointed out, if the surface of the cores were dried, water penetrated so rapidly into the surface that the latex particles could not form a continuous film. Unless the moisture content was

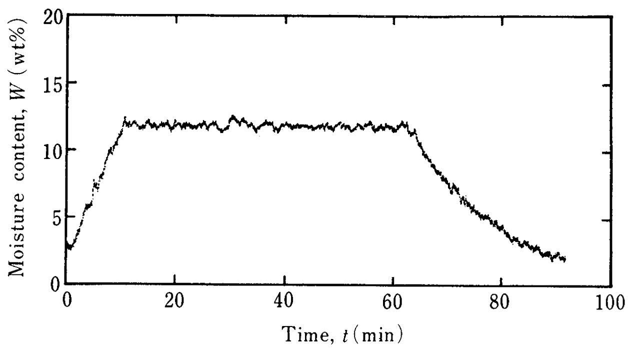

Fig. 7. The Temporal Change of Moisture Content in the Case of Moisture Feedback Control by PID Control

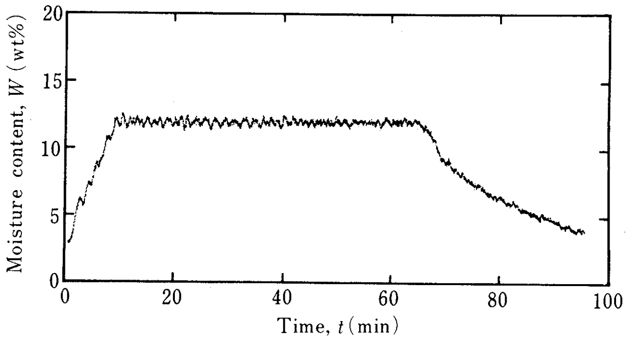

Fig. 8. The Temporal Change of Moisture Content in the Case of Moisture Feedback Control by On-Off Control

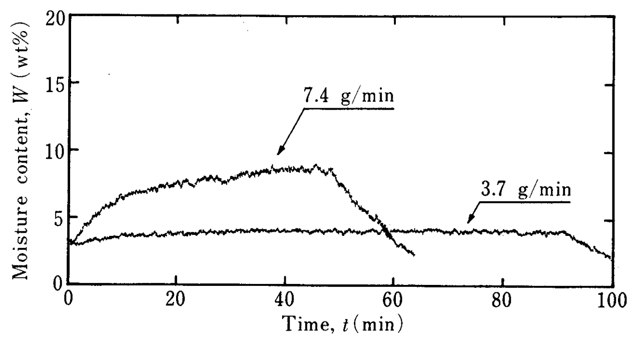

Fig. 9. The Temporal Change of Moisture Content without Moisture Control

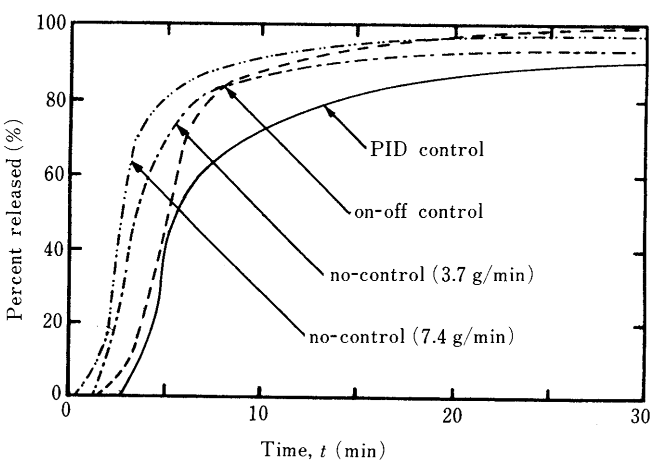

Fig. 10. Release of Pigment from the Coated Particles (pH = 7.2)

——, PID moisture control; ---, on-off moisture control; —·—, no-control at 3.7 g/min; -·-·-, no-control at 7.4 g/min.

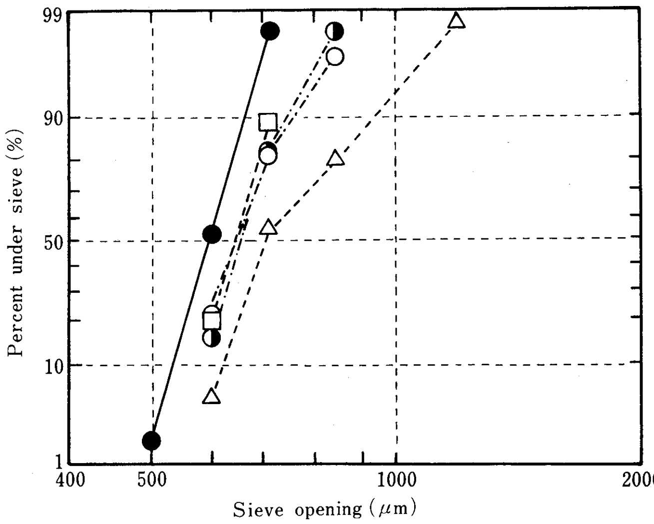

Fig. 11. Particle Size Distribution of the Coated Particles

●, core particle; □, PID control; △, on-off control; ◑, no-control at 7.4 g/min; ○, no-control at 3.7 g/min.

Table II. Agglomeration Tendency of the Coated Particles

Method	Coarse fraction (%)
Core particles	0
PID control	0.3
On-off control	20.2
No-control at 7.4 g/min	1.6
No-control at 3.7 g/min	3.2

controlled, due to the surface drying at the initial stage and of the high water absorbing power of the core particles, water existing between the layer polymer particles was removed by suction rather than by evaporation, and thus the polymer particles were deformed before having enough time and thermal energy to arrange periodically. In the no-control method, the reason that the 7.4 g/min showed a faster release rate than the 3.7 g/min was thought to be the initial drastic spraying onto the dry core surface.

In the case of moisture control, the on-off moisture control method indicated a considerably faster release rate than the PID control method. In the on-off control method, in spite of controlling the moisture content, particles were only dried while the electric supply was off, and the next time when the electric supply was on, dispersion was sprayed onto the dry surface. It was assumed that spraying onto the dry surface made it impossible to form a periodic arrangement and continuous film.

On the contrary, in the PID control method, since the surface of the core particles were continuously wet by the continual spraying and the moisture content needed for the periodic arrangement was kept constant, a continuous film was thought to be formed. Thus, it was concluded that the PID moisture control was an effective method for giving delayed release properties to the coated particles.

Figure 11 shows the particle size distribution of the coated particles made by each method and Table II lists the fraction over 850 μm of the coated particles, which shows the obvious agglomeration. Coated particles by the PID control method show the sharp particle size distribution with the lowest agglomeration. The no-control methods also indicate sharp particle size distribution with some agglomeration tendency. In the case of the on-off control method, the coarse fraction is considerably larger. It was found from the PID control method and the no-control method at 7.4 g/min, which had low agglomeration tendencies, that continuous wetting of the surface and keeping a high moisture content was effective for avoiding the agglomeration tendency. In the case of the on-off control method, however, although the moisture content was kept at a high constant value, there was a large agglomeration tendency. It was suggested that drying while stopping the dispersion spray promoted the agglomeration tendency. It can be said that repeating drastic spraying and drying in the on-off control method, or low moisture content in spite of continuous spraying in the no-control method at 3.7 g/min, could not avoid the agglomeration tendency. Thereby, it is suggested from the results obtained that moisture control by the PID control method is also effective in preventing the agglomeration tendency of the coated particles. Thus, it is concluded that controlling the moisture content continuously and making the interval between dampening and drying as brief as possible is necessary to produce coated particles which have favorable delayed release rates with low agglomeration tendencies.

Conclusions

In this paper, application of the IR moisture sensor to the aqueous coatings in the tumbling fluidized bed was discussed and the optimum method for producing the desired coated particles which rendered favorable delayed release rates with low agglomeration tendencies was reported. These were found to be as follows;

1) A high accuracy of measurement better than 0.5% was obtained in the case of applying the IR moisture sensor to the aqueous coating process. It was found that the application of the IR moisture sensor to the aqueous coating process was effective for measuring and controlling the moisture content during the operation.

2) The influence of the moisture control by the PID control method and the on-off control method on the drug release from coated particles and on the agglomeration tendency were investigated.

3) It was concluded that the coated particles made by the moisture PID control method exhibited excellent properties in delayed release without any agglomeration and was determined to be the optimum control method. Coated particles without controlled moisture content could not produce particles which had delayed release rates with low agglomeration tendencies.

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